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Port Hueneme, California 93043-4370

TECHNICAL REPORT
TR-2058-OCN

PHASE II DEMONSTRATION: SEAWATER HYDRAULIC TRANSFER PUMP

by

Greg Jokela and John Kunsemiller

April 1996

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U.S. Coast Guard R&D Center

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The Naval Facilities Engineering Service Center (NFESC) has successfully completed the Phase II demonstration of a seawater hydraulic-powered CCN-150 transfer pump. The objective of this demonstration was to compare performance parameters for the CCN-150 transfer pump powered by a Fenner F60 seawater motor against the transfer pump powered by the standard Rexroth oil hydraulic motor. Tests of the seawater hydraulic-powered CCN-150 transfer pump were conducted between 46 and 51 horsepower due to available power sources. Scaling of the transfer pump performance curves showed that the seawater hydraulic-powered CCN-150 transfer pump achieved equivalent performance to the oil hydraulic-powered CCN-150 pump system, confirming that a seawater hydraulic design for the CCN-150 transfer pump is practical using commercial components.

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EXECUTIVE SUMMARY

The Naval Facilities Engineering Service Center (NFESC) has successfully completed the Phase II demonstration of a seawater hydraulic-powered CCN-150 transfer pump. The objective of this demonstration was to compare performance parameters for the CCN-150 transfer pump powered by a Fenner F60 seawater motor against the transfer pump powered by the standard Rexroth oil hydraulic motor. Tests of the seawater hydraulic-powered CCN-150 transfer pump were conducted between 46 and 51 horsepower due to limitations in available power sources. The Fenner F60 motor is capable of up to 86 horsepower. Scaling of the transfer pump performance curves showed that the seawater hydraulic-powered CCN-150 transfer pump achieved equivalent performance to the oil hydraulic-powered CCN-150 pump system.

Based on results of the earlier Phase I concept development study performed for the United States Coast Guard (USCG) R&D Center, NFESC determined that an open circuit seawater hydraulic system configuration of the transfer pump system with a lightweight seawater hydraulic power source has the potential to provide a 3,000-pound savings over the present oil hydraulic system powered by the Navy MOD 6 hydraulic power source. This Phase II effort confirmed that a seawater hydraulic design for the CCN-150 transfer pump is practical using commercial components.

Use of thermoplastic hose achieved an additional savings of 1.8 pounds per foot of the three hydraulic hoses (supply, return, and drain). At typical hose lengths of 100 feet to 200 feet, this weight savings, not including hydraulic oil, provides a 180-pound to 360-pound reduction, thereby making a seawater hydraulic system easier for USCG Strike Teams to deploy.

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1.0 INTRODUCTION

The United States Coast Guard (USCG) National Strike Force (NSF) provides specialized spill response equipment for emergency offloading of grounded or otherwise stricken tank vessels. The NSF spill response equipment inventory includes the portable, hydraulically-operated, high capacity (1,800-gpm discharge flow at 20-psi discharge pressure) CCN-150 transfer pump system used in the offloading of tank vessels. This transfer pump system has been identified as a candidate for weight reduction to improve the NSF response capability by making system deployment easier for NSF Teams. The use of oil as the hydraulic fluid for this transfer pump system jeopardizes mission objectives by adding to system weight and increasing logistics handling. Most costly to achieving mission objectives are the resources and personnel required to transport the heavy transfer pump system.

In an effort to improve the NSF's ability to handle the CCN-150 transfer pump system, the USCG R&D Center contracted the Naval Facilities Engineering Service Center (NFESC) to conduct a Phase I study to determine whether or not a seawater hydraulic conversion of the oil hydraulic CCN-150 transfer pump system would reduce system weight. The Phase I study concluded that an open circuit seawater hydraulic system configuration of the transfer pump system with a lightweight hydraulic power source could provide a 3,000-pound savings over the present oil hydraulic system powered by the Navy MOD 6 hydraulic power source. Additionally, a seawater hydraulic system would improve system safety and environmental compliance through the elimination of hazardous hydraulic oil. The Phase I study recommended a Phase II demonstration of a seawater hydraulic-powered CCN-150 transfer pump.

This report documents the Phase II results of the demonstration of a seawater hydraulic-powered CCN-150 transfer pump. The guiding philosophy of the Phase II demonstration was the application of available commercial technology. No research or developmental work was necessary to demonstrate the CCN-150 transfer pump powered by a seawater hydraulic system.

2.0 BACKGROUND

NFESC's involvement in seawater hydraulics (SWH) began with the development of a seawater hydraulic multi-function tool system (MFTS) for use by Navy construction divers (Ref 1). One of the ways that the MFTS enhances Navy construction diver capability is by eliminating the rapid deterioration and intensified maintenance efforts associated with the use of oil hydraulic tools in the ocean.

More recent SWH development efforts include integrating seawater hydraulic components into an underwater work system demonstration package. This demonstration system successfully completed three months of operational testing in the Port Hueneme, California, harbor. It showed that a SWH system is capable of long term submergence and is not affected by seawater intrusion into the system as is typically the case for an oil hydraulic system.

To facilitate the seawater hydraulic-powered CCN-150 transfer pump demonstration, NFESC elected to utilize a Fenner F60 water motor converted for use with seawater. NFESC

had evaluated a Fenner 7-horsepower motor in a prior year. The Fenner motor design originally was developed at the National Engineering Laboratory (NEL), United Kingdom, and has seen many improvements over the years. These improvements include simplifying the design to decrease the parts count and using newer engineering polymers immune to corrosion.

3.0 OBJECTIVE

The objective of the Phase II effort was to compare performance parameters for the CCN-150 transfer pump powered by the Fenner F60 seawater motor against the pump powered by the Rexroth oil hydraulic motor.

4.0 COMPONENT DESCRIPTION AND MODIFICATIONS

4.1 CCN-150 Transfer Pump

4.1.1 General Description. The submersible CCN-150 transfer pump shown in Figure 1 is part of the Navy and Coast Guard petroleum, oils, and lubricants (POL) transfer system. The CCN-150 is a single stage centrifugal pump designed for high pumping efficiency and prolonged immersion in seawater and petroleum products. For purposes of this demonstration, NFESC conducted tests using a CCN-150-1C model transfer pump. In this report, a generic CCN-150 designation will be used unless a specific reference to model number is required. The CCN-150 pump characteristics are listed in Table 1.

Table 1. CCN-150-1C Transfer
Pump Characteristics

Performance	1,800 gpm @20 psi
Weight	278.5 pounds
Height	41.25 inches
Diameter	11.88 inches

The CCN-150-1C pump casing is made of cast nickel aluminum bronze alloy which is designed to resist prolonged immersion in seawater and petroleum products. Internal to the pump unit is a high pressure hydraulic motor that drives the single stage impeller. The impeller shaft is supported by a heavy duty ball bearing at one end and a carbon-impregnated sleeve bearing at the other end. The ball bearing is lubricated and cooled by leakage oil from the hydraulic motor. The carbon-impregnated bushing is lubricated and cooled by the cargo fluid being pumped. The pump is fitted with a strainer to prevent particles from entering the pump that would degrade pump performance by damage or obstruction.

Associated hoses consist of the cargo discharge hose for the pump and the hydraulic hoses for the motor operation. The 6-inch-diameter discharge hose is suitable for immersion in

seawater, petroleum products, and light chemicals. All discharge hoses are supplied with male and female cam-locking connectors. The hydraulic hoses for supply, return, and case drain are wire-braided reinforced rubber hose with quick-disconnect couplers for mating hose sections.

4.1.2 CCN-150-1C Modifications. Minor modifications to the CCN-150 housing were necessary to accommodate the Fenner F60 seawater hydraulic motor. The CCN-150 is powered by a bent axis oil hydraulic motor which is isolated (by means of a motor chamber) from the cargo being pumped. The motor chamber located inside the CCN-150 casing is shown in the top portion of Figure 2 (labeled "before machining"). Because the Fenner F60 seawater motor is a straight axis motor design, it did not fit within the motor chamber volume. Since the Fenner F60 motor housing is stainless steel and not affected by exposure to the pumped cargo, the isolated motor chamber in the CCN-150 was not necessary and was removed as shown in Figure 2 (labeled "after machining").

A porting block was designed to provide a fluid path from the rear of the Fenner F60 motor to an offset opening in the CCN-150 pump housing. Figure 3 is a photo of the disassembled seawater hydraulic CCN-150 pump showing the 316 stainless steel porting block mounted on the motor. Figure 4 is a line drawing cutaway showing motor placement within the CCN-150 housing.

The pump impeller shaft radial ball bearing was originally cooled and lubricated by leakage flow from the oil hydraulic motor. Elimination of the oil hydraulic motor, and thus the supply of lubricating oil, required enclosing the impeller shaft radial ball bearing in a sealed reservoir of lubricating oil. Sealing the reservoir was accomplished by plugging the ports used to channel the leakage flow. Because of the limited testing planned, cooling the bearing was not necessary for this demonstration. The original mechanical sealing arrangement between the pump bowl and the impeller, and the O-ring seal at the motor end, was not changed for the Fenner F60 motor replacement.

4.2 Fenner F60 Motor Description

The Fenner model F60 axial piston motor is shown disassembled in Figure 5. The motor operates when high pressure seawater is supplied to the inlet port at the port end cover. An internal port plate routes the fluid from the inlet port to the cylinder block while acting as a bearing surface for the cylinder block. The high pressure seawater forces individual pistons within the cylinder block to move against the face of the cam, transferring the linear motion of the piston into rotary motion of the cylinder block. The seawater is then channeled back through the port plate to the outlet port on the port end cover. A splined intermediate shaft connects the rotary motion of the cylinder block to the output shaft. The Fenner motor characteristics are listed in Table 2 and are compared to the Rexroth oil hydraulic motor used in the CCN-150.

The design of the Fenner motor makes good use of polymers to improve wear characteristics and minimize component weight. At 55 pounds, the Fenner motor is 4 pounds heavier than the Rexroth motor it replaces. Weight reductions may be achieved through application of composites for the motor housing. The cylinder block housing is an ideal candidate for composites because the cylindrical housing sees minimal loads and no high system pressures. The front and rear housing plates may also benefit from the weight savings provided through composite technology.

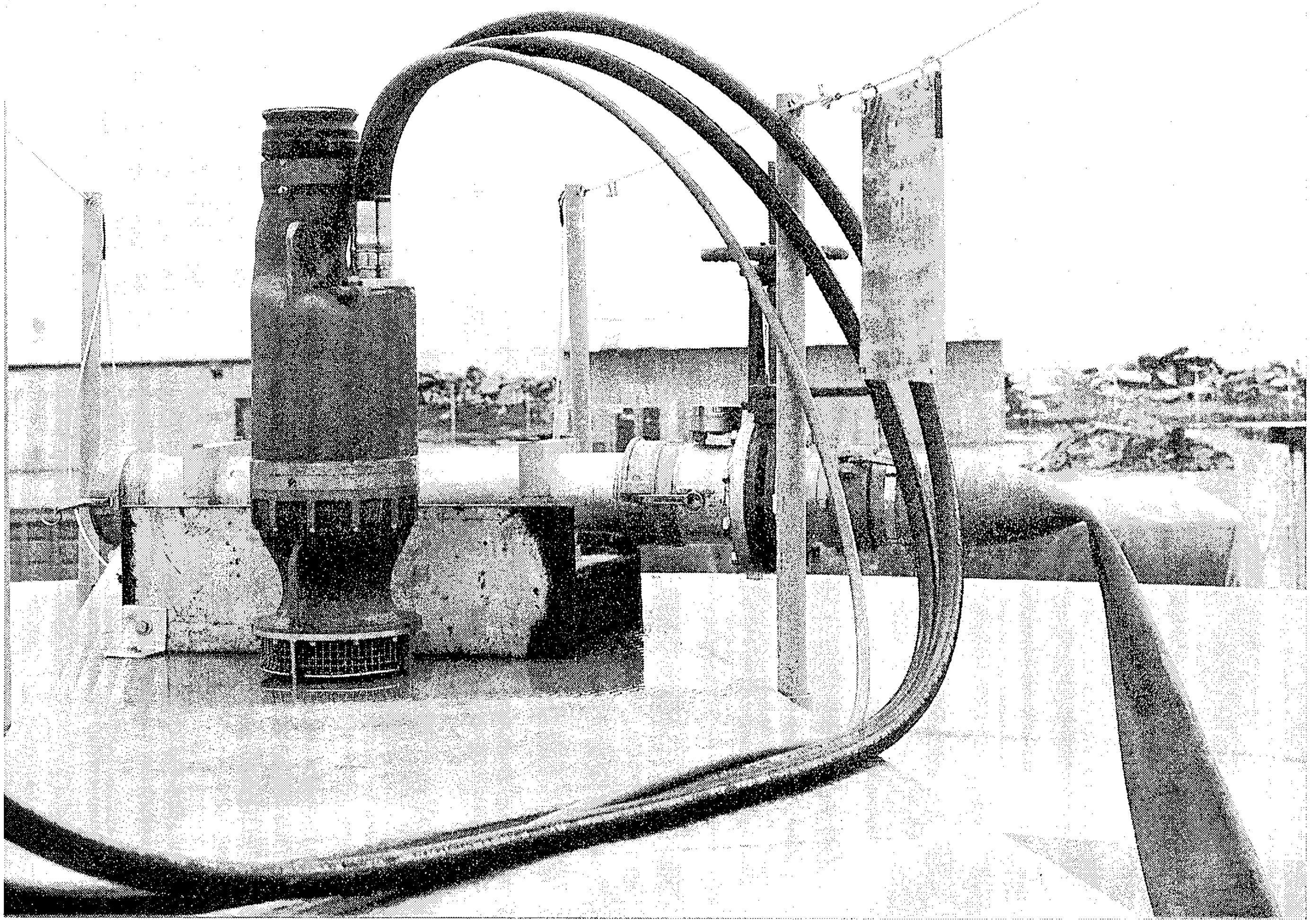

Figure 1
CCN-150-1C transfer pump.

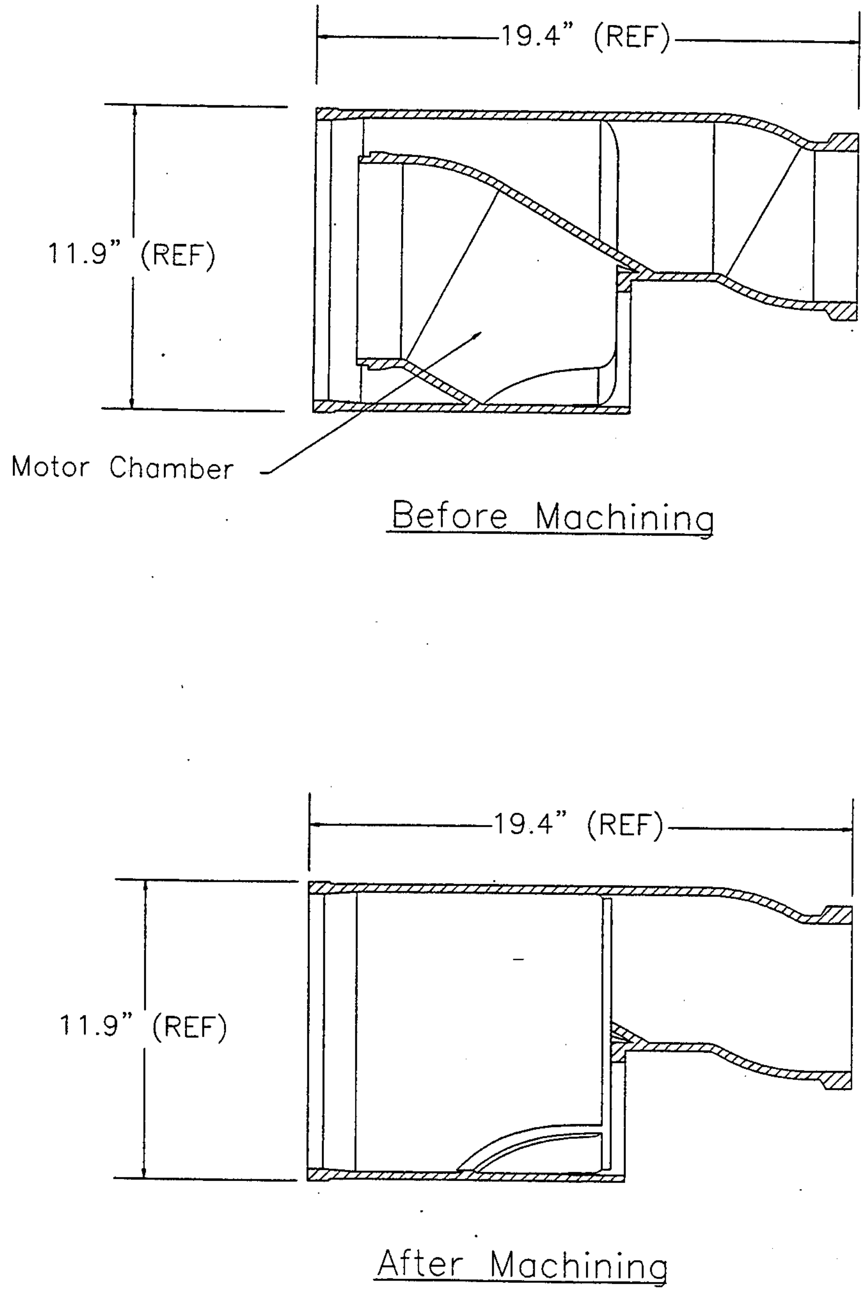

Figure 2
CCN-150 pump housing before and after modifications.

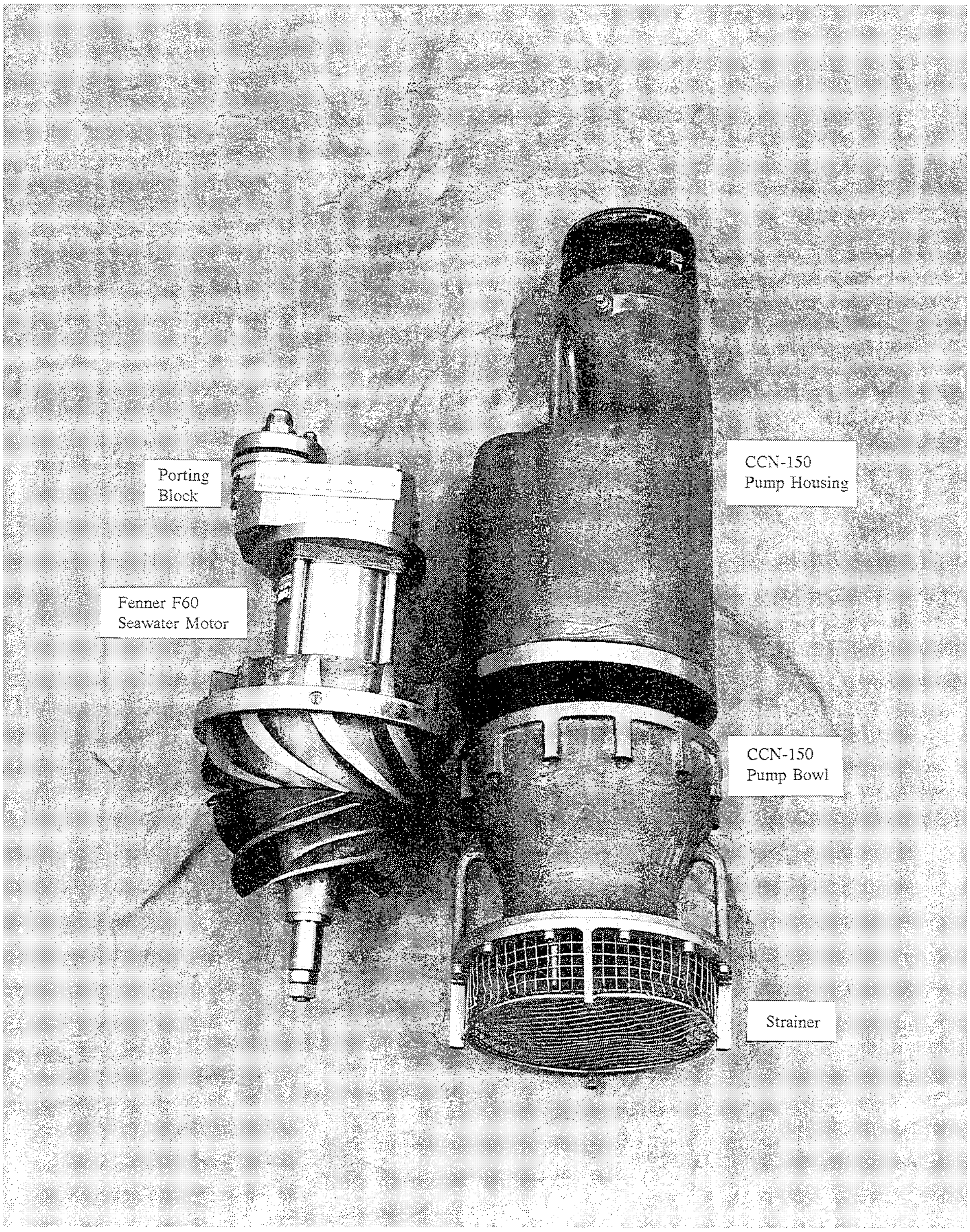

Figure 3
CCN-150 transfer pump and Fenner F60 seawater motor - exploded view.

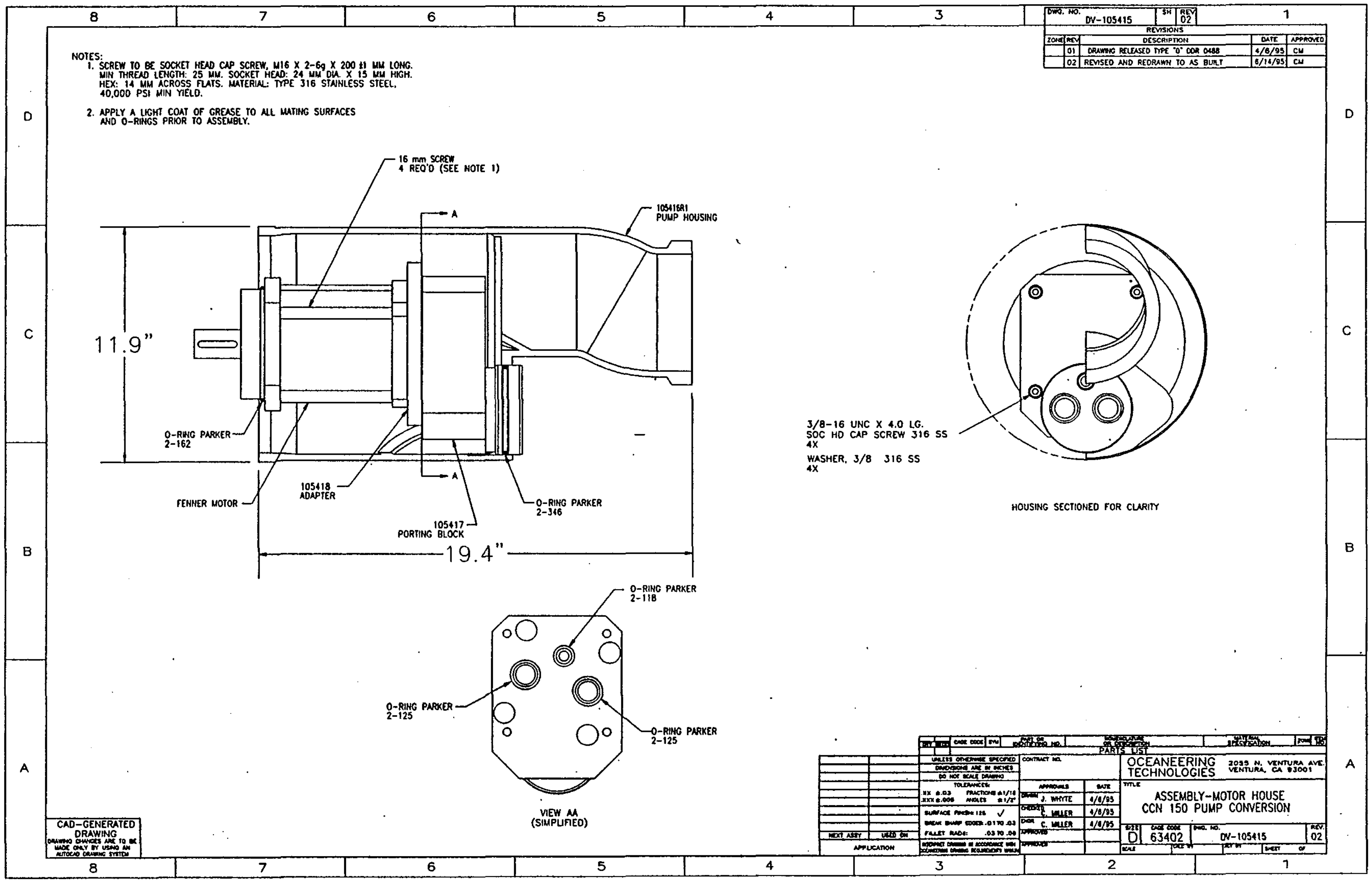

Figure 4
CCN-140 motor housing assembly.

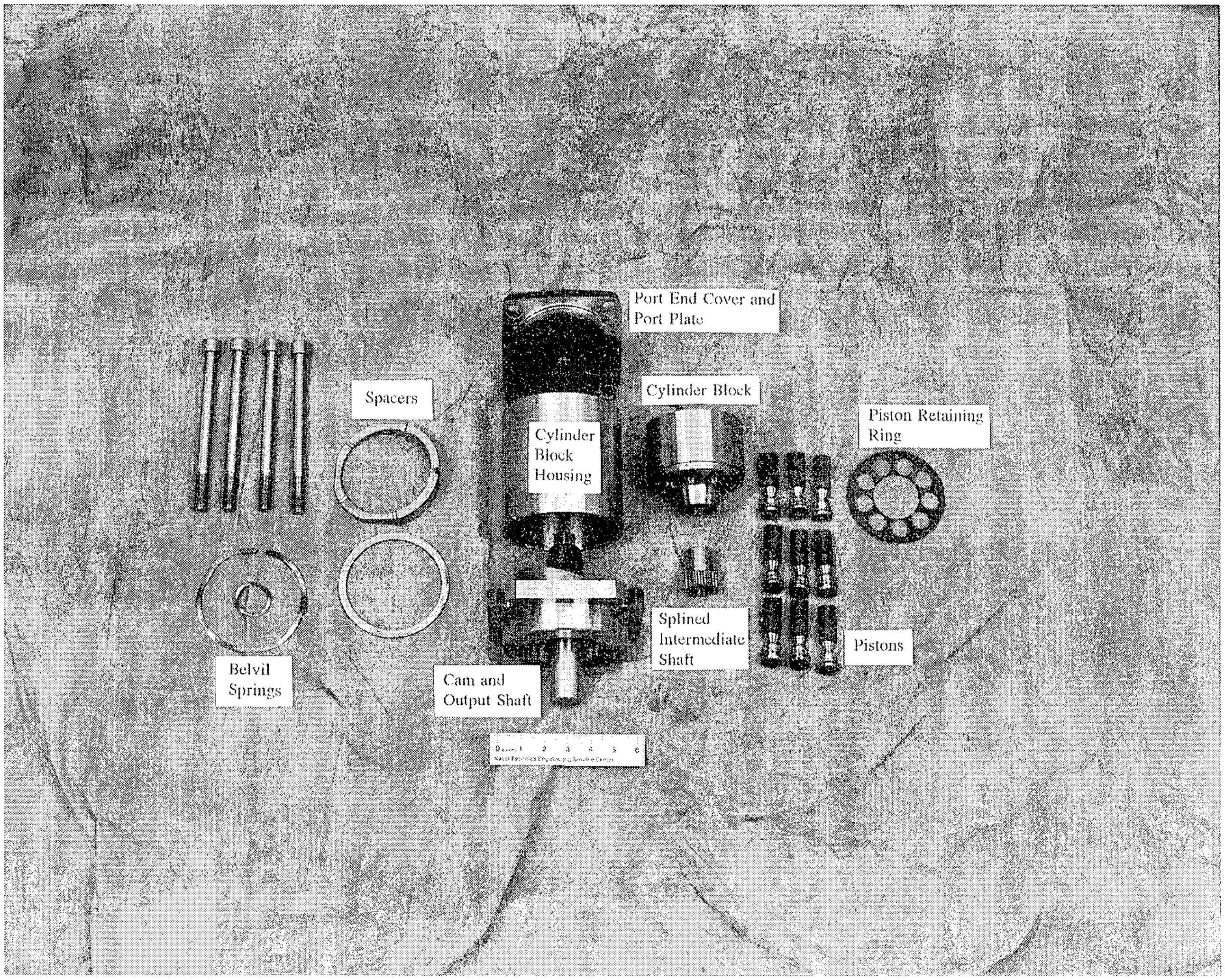

Figure 5
Fenner F60 seawater motor - exploded view.

Table 2. Motor Comparison

Characteristics	Fenner	Rexroth
Displacement (in.^{3}/rev)	4.29	4.90
Speed (rpm)	3,200	3,350
Supply Flow (gpm)	59	71
Supply Pressure (psi)	2,030	2,370
Torque (ft-lb)	114 @ 2,030 psi	150 @ 2,370 psi
Width (in.)	6.75	5.5
Length (in.)	10.5	10.2
Weight (lb)	55	51
Nominal Power (hp)	69 @ 2,030 psi	96 @ 2,370 psi

The Fenner F60 motor was originally designed to operate on fresh water. Fenner made material upgrades to satisfy requirements for seawater operation. All 304 stainless steel and aluminum parts were replaced with 316 stainless steel parts to increase the corrosion resistance. Polyetheretherkeytone (PEEK) was used for bearing surfaces at all moving part interfaces and for sealing surfaces, so no changes or modifications were required for seawater operation.

4.3 Synflex Thermoplastic Hose

The Phase I feasibility study concluded that a 370-pound weight savings could be achieved with the present oil hydraulic transfer pump system if thermoplastic hose was used instead of the wire-braided reinforced rubber hose. This savings was based on 1-inch-diameter supply/return and 0.5-inch-diameter case drain hose sizes. The Phase I study also recommended the use of 1.25-inch-diameter return line size to reduce line back pressure, thereby improving system performance. However, the lower viscosity of seawater compared to hydraulic oil allows the 1-inch-diameter hose size to be used for the supply and return lines without causing adverse pressure drop.

For the Phase II demonstration, thermoplastic hose was used for the supply, return, and motor case drain lines. A 1-inch-diameter Synflex 3350 thermoplastic hose was used for the supply and return lines. Because the motor case drain flow rate is low, no change in case drain hose size was warranted. A 0.5-inch-diameter Aeroquip thermoplastic hose was used for the motor case drain line. Table 3 shows the specifications for the thermoplastic hose in comparison to the wire-braided reinforced rubber hose currently used. The thermoplastic hose provides a total savings of 1.8-pounds-per-foot length for the three hydraulic hoses.

Table 3. Hose Specification Comparison

Supply and Return	Synflex 3350 Thermoplastic	Aeroquip FC324 Wire-Braided
Nominal I.D. (in.)	1	1
Maximum O.D. (in.)	1.48	1.48
Minimum Bend Radius (in.)	8.0	12.0
Working Pressure (psi)	3,000	4,000
Minimum Burst Pressure (psi)	12,000	16,000
Weight per 100 Feet (lb)	42.0	122.0
Motor Case Drain	**Aeroquip FC375 Thermoplastic**	**Aeroquip FC194 Wire-Braided**
Nominal I.D. (in.)	0.5	0.5
Maximum O.D. (in.)	0.81	0.90
Minimum Bend Radius (in.)	4.0	7.0
Working Pressure (psi)	3,500	2,500
Minimum Burst Pressure (psi)	14,000	10,000
Weight per 100 Feet (lb)	14.0	38.0

The Synflex 3350 thermoplastic hose has an inner nylon-lined core tube with two layers of synthetic-fiber reinforcement and a polyurethane cover. The synthetic-fiber reinforcement provides added pressure and flex life, and the fibers will not rust or flex fatigue like wire-braided reinforcement. The Synflex hose has a lower working pressure rating than the Aeroquip wire-braided hose, however, the seawater system design pressure is safely within the working pressure. A polyurethane cover was chosen over the polyester cover because polyurethane provides excellent abrasion resistance and flexibility.

5.0 TEST ARRANGEMENTS

Different test arrangements were utilized to: (1) evaluate the Fenner F60 motor, and (2) demonstrate a seawater hydraulic-powered CCN-150 transfer pump. The setup for evaluating the Fenner F60 motor will be referred to as the laboratory test setup and the setup to demonstrate the CCN-150 will be referred to as the full scale test setup. Both tests are discussed in detail below. Due to available power source equipment limitations, all tests were performed at pressures of 2,000 psi or less.

5.1 Laboratory Test Setup - Fenner Motor Test

The laboratory test setup schematic for the Fenner motor is shown in Figure 6. Table 4 presents the test parameter matrix showing the motor inputs and their respective motor output. Three Harben model 822 radial piston pumps supplied flow while a pressure-relief valve regulated pressure to the Fenner motor. Analog pressure and flow gages were used to measure supply pressure and flow, return pressure, and case drain flow. A Clayton model CAM-50 dynamometer served as the external load with a High Technics data acquisition unit monitoring the torque. A strobe light was used to obtain shaft speed.

Torque, shaft speed, input flow, leakage flow, and return pressure data were measured at 500-psi, 1,000-psi, 1,500-psi, and 2,000-psi system pressures. Operating the three Harben pumps in sequence allowed evaluation of motor performance for a selection of flow rates and pressures. Once data were obtained for the 1- to 18-gpm flow rate (one Harben pump), the second Harben pump was operated to supply 19 to 36 gpm. The sequence of loading the dynamometer at the four selected system pressures was repeated. Finally, the third Harben unit was operated to supply up to 54 gpm and the loading sequence was repeated. Note that this flow rate is below the 59-gpm rating of the Fenner F60 design, therefore, full motor performance was not evaluated.

Table 4. Test Parameter Matrix

Motor Input	Motor Output
Pressure	Torque (Load)
Flow	Speed

5.2 Full Scale Test Setup - Pump Performance Test

The full scale test setup, Figure 7, consisted of transfer pump operation in NFESC's 60,000-gallon Shallow Water Test Facility (SWTF). The seawater in the SWTF served as the pumped cargo source for the transfer pump and as the hydraulic supply for the Fenner F60 seawater motor. The CCN-150 discharge was channeled through a 6-inch hose to a 2-foot-long section of 6-inch aluminum pipe where an acoustic flow meter was used to measure discharge flow rate. A 6-inch-diameter knife valve was used as the load valve to create restriction for the CCN-150 transfer pump. Discharge pressure was measured using an analog pressure gage mounted in the aluminum pipe section. From the load valve, the discharge from the CCN-150 transfer pump was returned to the tank.

A typical test included operating the Harben pumps in sequence to obtain the three flow ranges while loading the CCN-150 pump and measuring CCN-150 discharge flow, head, and pump-shaft speed for each flow range. Pump-shaft speed was measured with a proximity sensor installed in the pump bowl. Shaft speed and hydraulic supply flow and pressure were used to gage the Fenner motor performance during the full scale test.

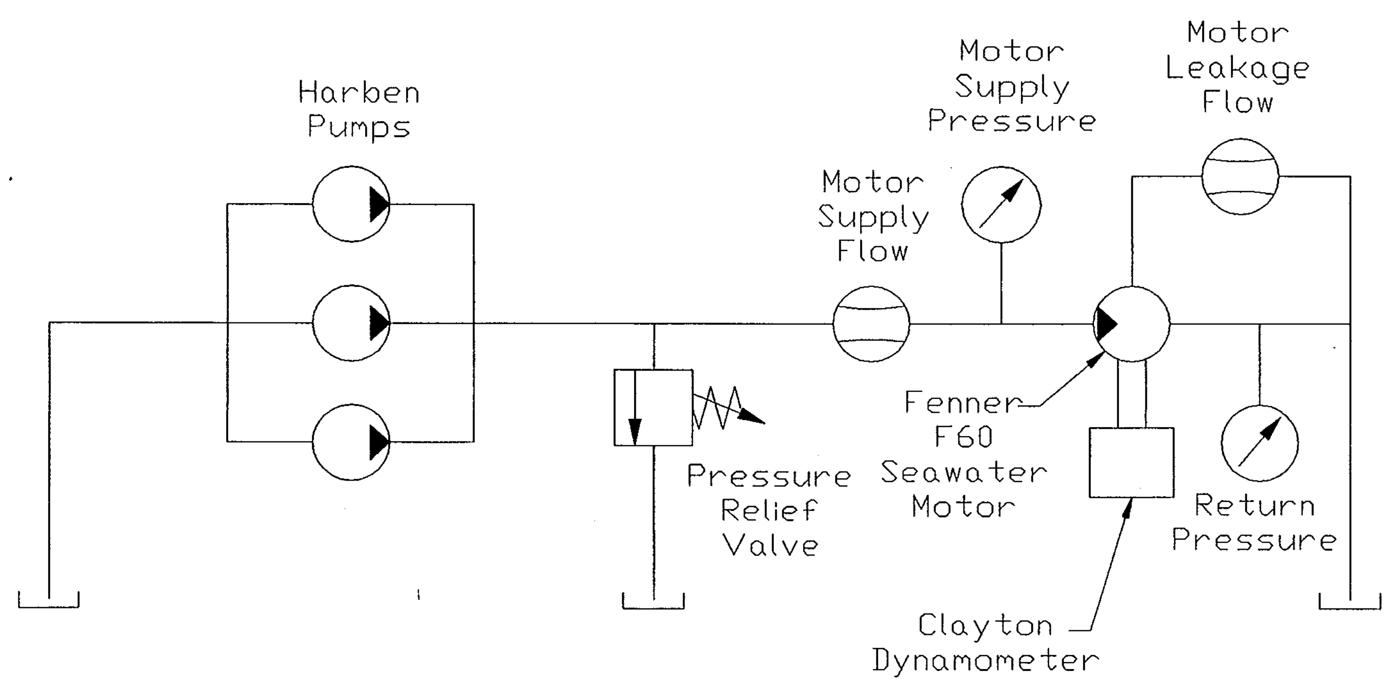

Figure 6
Laboratory test schematic.

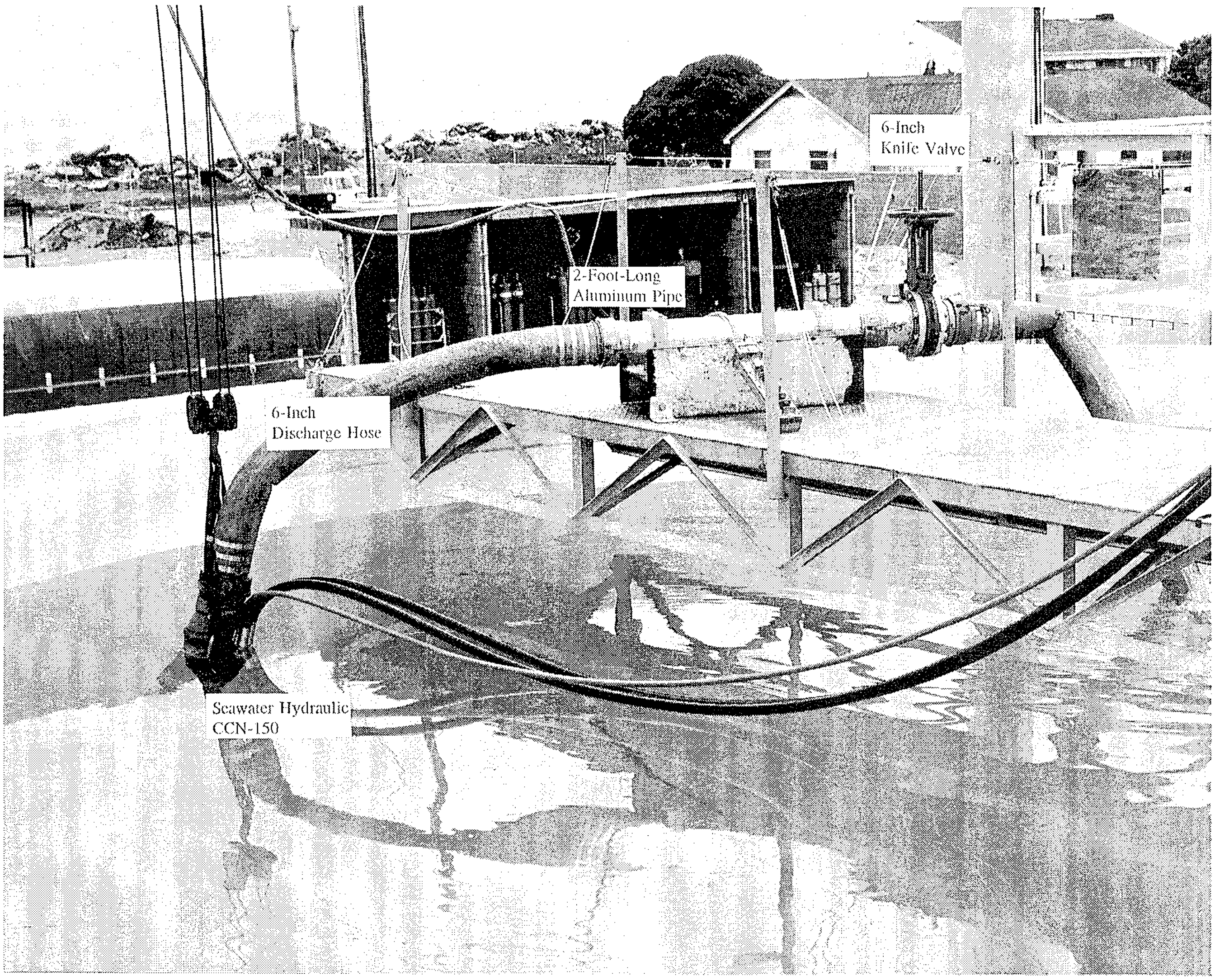

Figure 7
Full scale test setup.

6.0 RESULTS

The results from the demonstration of the seawater hydraulic conversion for the CCN-150 are discussed below concerning the modified CCN-150 performance with the Fenner F60 seawater motor, the Fenner F60 performance, and issues dealing with the Synflex hose.

6.1 Fenner F60 Performance

Motor performance identified by volumetric, mechanical, and overall efficiencies is discussed below. Motor data in tabular form are provided in Appendix A.

6.1.1 Volumetric Efficiency. Volumetric efficiency quantifies the power losses due to internal leakage in the motor. For example, leakage around pistons and porting plates is included in volumetric efficiency. Excessive internal leakage would show up as a large flow variation and would likely increase with pressure, possibly indicative of wear in the pistons or the port plate. At a given speed, volumetric efficiency is the ratio of actual flow to theoretical flow. The theoretical displacement of the F60 motor is 4.29 in.^{3}/rev (70.27 cc/rev).

Figure 8 plots the volumetric efficiency measured at several supply pressures against motor shaft speed. The figure shows that volumetric efficiency numbers increase a few percent with increasing shaft speed, tending to level out at 85 percent. For a positive displacement piston motor, 85 percent volumetric efficiency is 10 percent less than expected. A possible reason for this excessive leakage is too large a clearance between the cylinder block and the porting plate. This is consistent with the lower volumetric efficiencies calculated for motor shaft speeds between 500 and 700 rpm where the slower shaft speed allows the motor to dwell longer on port to port leakage paths.

6.1.2 Mechanical Efficiency. Mechanical efficiency identifies power loss due to internal frictional forces and is calculated for a motor as the ratio of the delivered torque to the theoretical torque. Examples of internal friction losses include bearing losses and friction between the pistons and the cylinder block.

Figure 9 plots the mechanical efficiency measured at several supply pressures against motor shaft speed. The figure shows that mechanical efficiency numbers are generally under 90 percent and tend to decrease as shaft speed increases. This is less than what is expected of a positive displacement piston motor. A 95 percent mechanical efficiency is more often the case with frictional losses remaining constant across the design speed range. The slight decrease in mechanical efficiency for increasing shaft speed has not been explained and could be due to measurement errors.

The data for the 500-psi operating pressure show a marked reduction in mechanical efficiency across the speed range when compared to the other pressure curves. Possibly, the frictional forces are a greater percentage of the available torque at this low pressure. As pressure is increased, friction decreases due to better lubrication of the contact surfaces.

6.1.3 Overall Efficiency. Overall efficiency gives the total performance of the motor by including mechanical and volumetric losses. Overall efficiency is the product of the mechanical and volumetric efficiencies. In Figure 10, the four curves represent the overall efficiency at

operating pressures of 500 psi, 1,000 psi, 1,500 psi, and 2,000 psi, and show the influence of the low mechanical and volumetric efficiencies. Most of the data indicate about a 75 percent overall efficiency for the Fenner F60 seawater motor.

6.2 CCN-150 Performance

The performance of the seawater hydraulic-powered CCN-150 transfer pump nearly matched the performance baseline of the oil hydraulic-powered CCN-150. Because of power supply limitations, it was not possible to duplicate exact pumping conditions. Figure 11 compares discharge pressure versus discharge flow rate performance data for the oil hydraulic-powered and the seawater hydraulic-powered CCN-150 transfer pumps. CCN-150 data in tabular form are provided in Appendix B.

The oil hydraulic transfer pump curve (shown as the upper curve in Figure 11) was derived from data for pumping seawater (Ref 2) and is representative of the CCN-150 characteristics when using the Navy MOD 6 oil hydraulic power supply. This performance curve is based on a supply pressure ranging from 2,000 to 2,300 psi and a hydraulic flow rate of 45 to 47 gpm (shaft speed is estimated at 2,200 to 2,400 rpm). Under these conditions, approximately 63 horsepower is supplied to the Rexroth hydraulic motor.

The seawater hydraulic transfer pump curve (shown as the lower curve in Figure 11) was generated from laboratory and full scale empirical data. This performance curve is based on a supply pressure ranging from 1,775 to 1,950 psi and a hydraulic flow rate of 45 gpm. The measured shaft speed was 2,105 to 2,181 rpm. The power supplied to the Fenner F60 seawater motor was approximately 51 horsepower. The results are summarized in Table 5.

Table 5. Comparison of Motor Operating Conditions

Parameter	Rexroth Motor Oil	Fenner Motor Seawater	Reduction (%)
Pressure (psi)	2,000 to 2,300	1,775 to 1,950	11.2 to 15.2
Flow (gpm)	45 to 47	45 to 46	0 to 2.1
Shaft Speed (rpm)	2,200 to 2,400	2,105 to 2,181	4.3 to 9.1
Horsepower (hp)	52.5 to 63.0	46.6 to 51.2	11.2 to 18.7

Looking at Figure 11, the lower discharge pressure at constant discharge flow for the seawater hydraulic-powered CCN-150 is attributed to the combination of lower horsepower operation and the modifications to the CCN-150 housing required for mounting the Fenner F60 motor. The CCN-150-1C pump housing with an internal chamber for the oil hydraulic motor provided a clean, unobstructed path for fluid flow. Modifications for the Fenner F60 motor required removal of the internal motor housing and the addition of a porting block. The modifications resulted in greater internal frictional forces acting to create turbulence and to increase pressure losses in the pumped fluid, particularly at greater cargo volume flow rates.

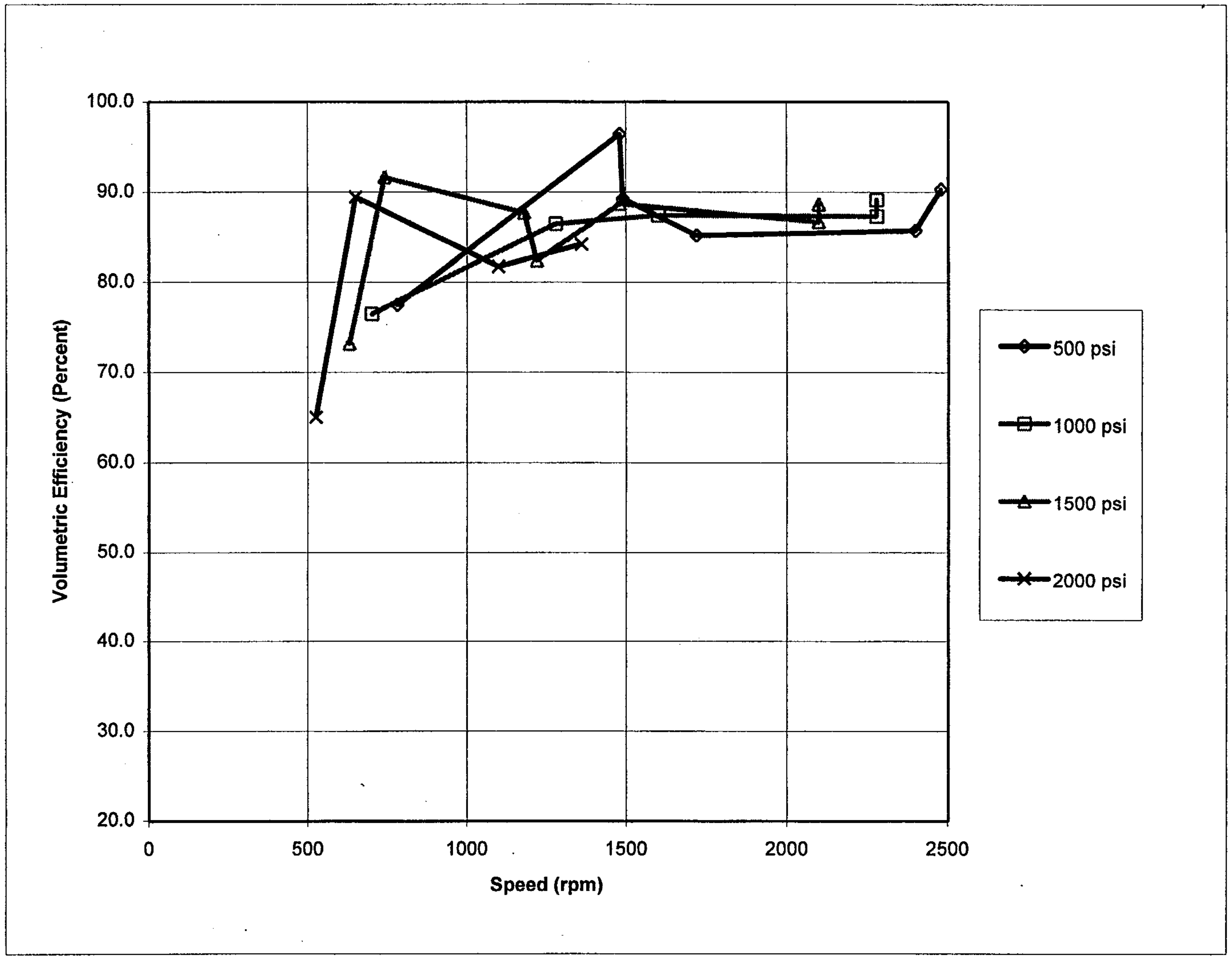

Figure 8
Fenner F60 motor volumetric efficiency.

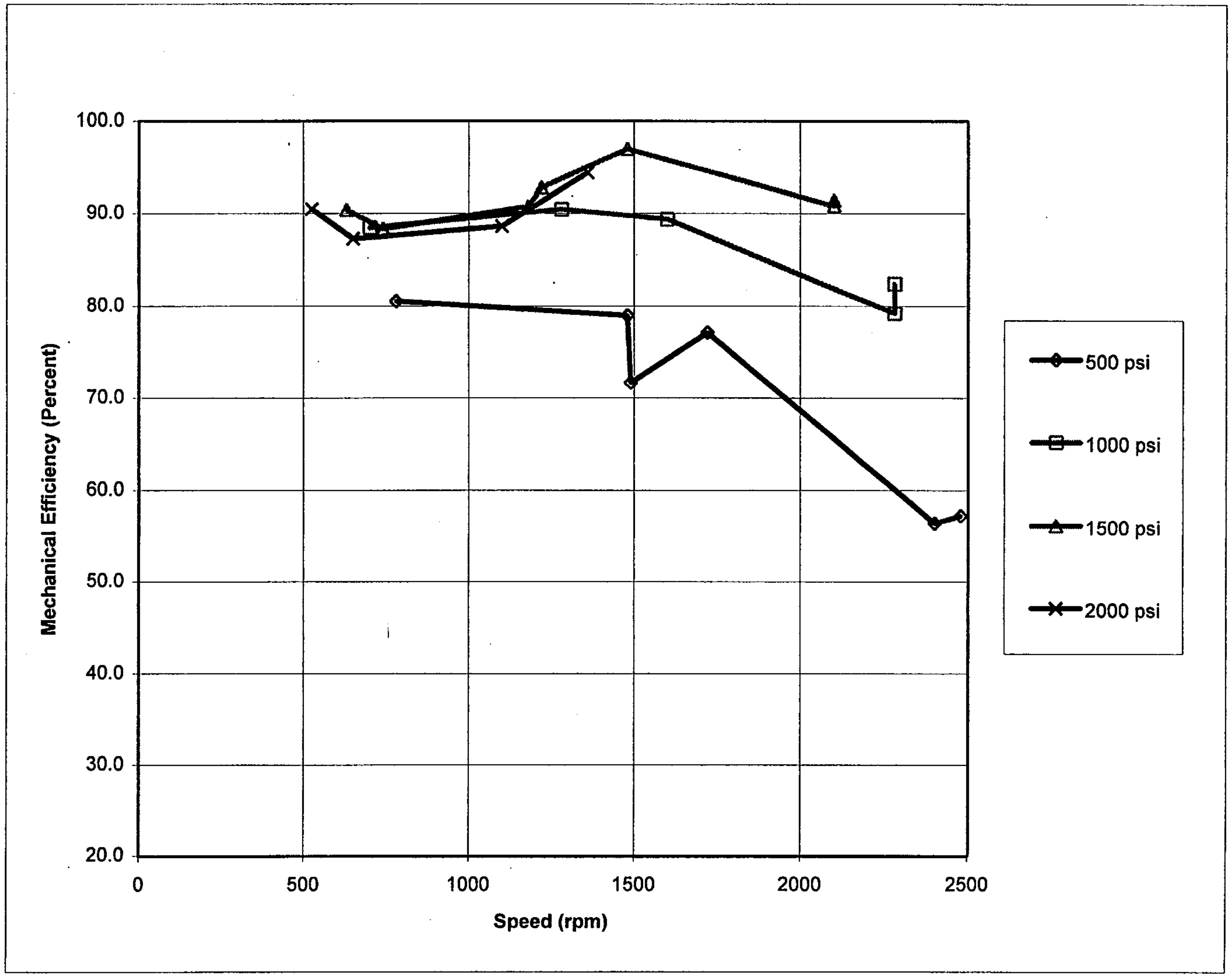

Figure 9
Fenner F60 motor mechanical efficiency.

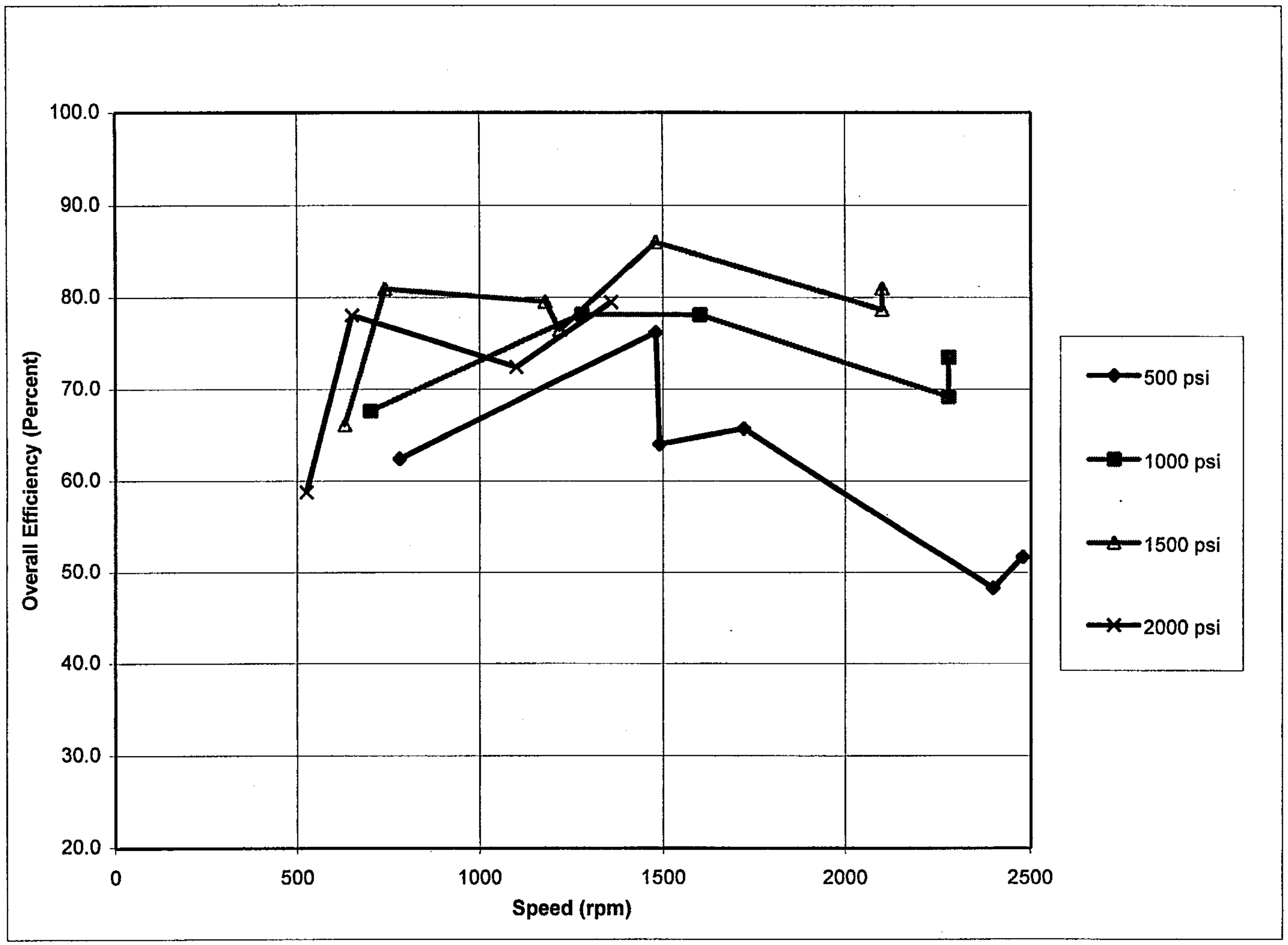

Figure 10
Fenner F60 motor overall efficiency.

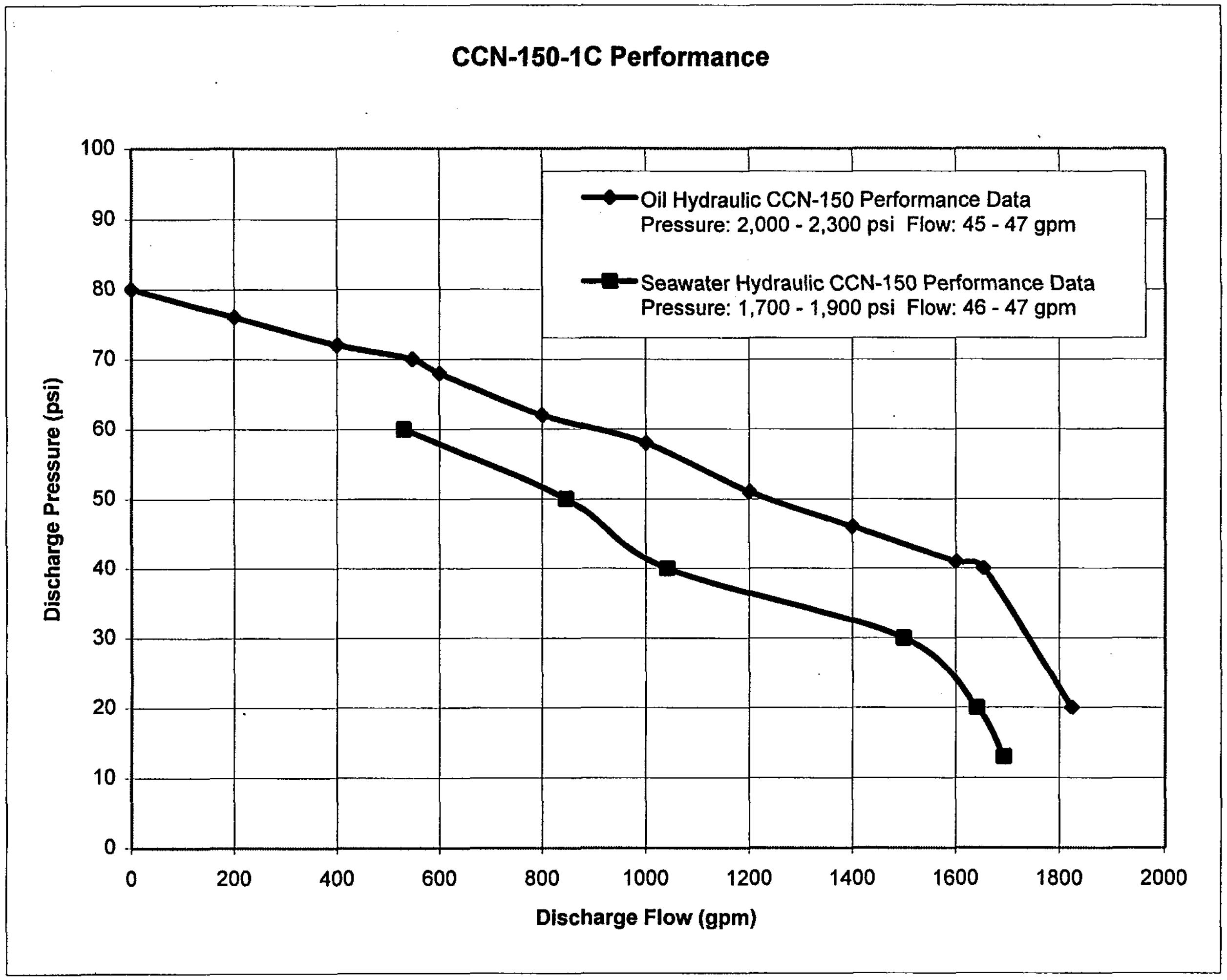

Figure 11
CCN-150 flow performance comparison using oil hydraulic motor and Fenner seawater motor.

6.3 Synflex Thermoplastic Hose

The performance issues for the Synflex hose involve abrasion and handling characteristics. The thermoplastic hose showed excellent abrasion resistance characteristics when laid out across asphalt pavement and concrete walkways during testing. The Synflex hose experienced no appreciable wear over several months of testing the Fenner motor and the CCN-150 transfer pump. Wear is not expected to be a problem when used across non-skid decking material aboard ships.

The light weight of the hose made handling easy with the exception that the Synflex hose showed a tendency to kink. Kinking occurred close to the fittings and in middle sections when the hose was uncoiled to make connections. NFESC frequently uses smaller diameter thermoplastic hose (0.25-inch through 0.75-inch ID) and has not experienced this handling problem. The 0.5-inch hose used for the motor case drain did not kink during the tests. Synflex application engineers state that the larger thermoplastic hose may experience occasional kinking without degradation or loss in pressure rating.

7.0 ANALYSIS

The Phase II demonstration of the seawater hydraulic conversion for the CCN-150 pump showed that the Fenner F60 seawater motor is an excellent replacement for the oil hydraulic motor. This demonstration has served as a design guide for full scale motor specifications for the seawater hydraulic-powered CCN-150 transfer pump. The following sections analyze system sizing and cold weather operation of a seawater hydraulic-powered CCN-150 transfer pump system.

7.1 System Sizing

The Phase II demonstration of the seawater hydraulic-powered CCN-150 transfer pump provided system performance data for a motor input horsepower between 46 and 51 horsepower. The Fenner F60 seawater motor is rated for 59 gpm at 2,500 psi (equating to 86 horsepower). Therefore, to adequately compare the performance of the seawater hydraulic-powered CCN-150, the performance data were scaled, using the affinity law, to an equivalent oil hydraulic-powered CCN-150 performance.

Figure 12 is a plot of several curves showing the scaling of the seawater hydraulic-powered CCN-150 performance to equivalent oil hydraulic-powered CCN-150 performance. The CCN-150 pump performance when operated with the Fenner F60 motor at nominally 2,150 rpm is shown in the lower curve. The oil hydraulic-powered CCN-150 performance at approximately 2,200 to 2,400 rpm is shown in the second curve from bottom. Using the affinity law relationships for centrifugal pumps, the performance of the seawater modified CCN-150 transfer pump was scaled to an operating speed of 2,400 rpm.

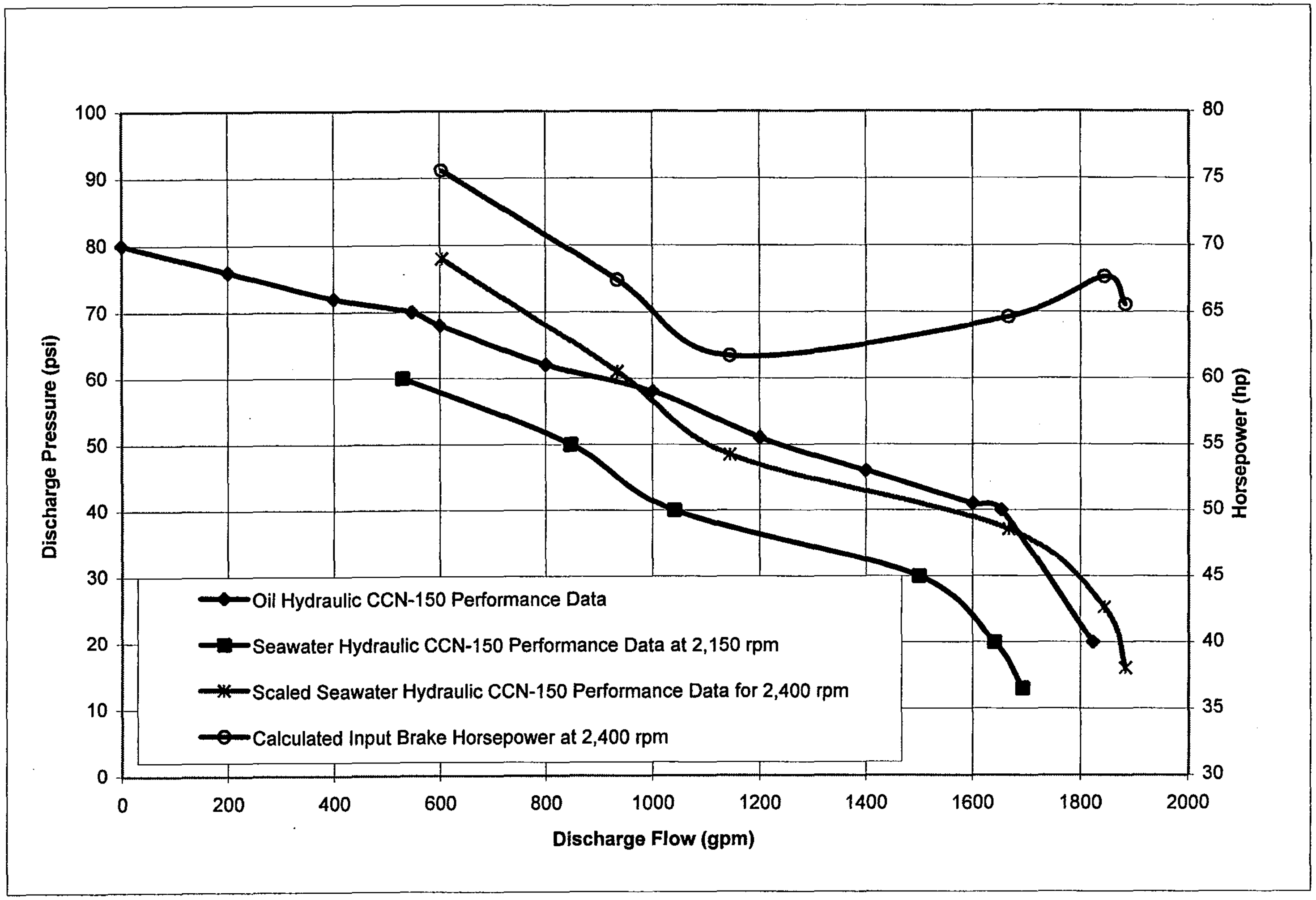

Figure 12
Scaling the seawater hydraulic CCN-150 performance
to match the oil hydraulic CCN-150 performance data.

The affinity law for variations in speed (constant impeller diameter) is:

$$S_1/S_2 = Q_1/Q_2 = (H_1)^{1/2}/(H_2)^{1/2}$$

where S = speed in rpm
Q = capacities in gpm
H = head in feet

The scaled performance of the seawater hydraulic-powered CCN-150 transfer pump using the Fenner F60 motor operating at a speed of 2,400 rpm is plotted in Figure 12. The performance level represented by this curve is nearly equivalent to the oil hydraulic-powered CCN-150 performance curve.

The input horsepower requirements represented by the scaled seawater hydraulic CCN-150 performance curve were estimated by applying the measured CCN-150 efficiency data to the delivered horsepower. The 250-rpm speed difference between the data at 2,150 rpm and the scaled 2,400-rpm condition is considered insignificant for this approximation representing less than a 10 percent difference in horsepower. The efficiency data of the tested CCN-150 are products of the efficiency of the impeller and the overall efficiency of the F60 hydraulic motor.

The upper curve in Figure 12 is the brake horsepower required to operate the Fenner motor at 2,400 rpm using the pump efficiency data. The brake horsepower curve shows that 76 horsepower is required to achieve full seawater hydraulic-powered CCN-150 transfer pump performance. Allowing for an additional 10 percent for transmission losses, 80 to 85 horsepower would be required at the hydraulic power source.

The Coast Guard currently has two power sources that can operate the CCN-150 transfer pump. Table 6 is a comparison of the specifications for the Navy MOD 6 and the Coast Guard power sources. Because of the MOD 6 power source weight, it is not a good candidate for a remote response team. The Coast Guard's lighter weight power source is powered by a Duetz four stroke diesel engine. Conversion of this power source or development of a power source around the Duetz engine is a viable alternative for an 80- to 85-horsepower seawater system.

Table 6. Oil Hydraulic Power Source Comparison

Power Source	Weight (lb)	Dimensions (in.)	Flow Rate Capability	Power (hp)
Navy MOD 6	4,100	98x34x58	52 gpm @ 2,500 psi	75.8
Coast Guard Light Weight	1,735	68x40x48	50 gpm @ 3,000 psi	87.5

Because of the potential for operation in an explosive atmosphere, the Coast Guard uses a hydraulic starter to start the diesel engines on the MOD 6 and Duetz power sources. Ether is used in colder climates to assist in diesel start because of the absence of glow plugs. The

hydraulic starter consists of a hand pump that draws fluid from the hydraulic system oil reservoir to pressurize an accumulator. Release of the accumulator charge drives a small hydraulic motor to crank the engine for starting. Conversion of this starting system to a seawater hydraulic system is well within the available technology. Selection of a small displacement Fenner motor would be adequate for such a conversion.

7.2 Temperature

The freezing temperature of seawater falls within the desired transfer pump operating envelope of 0°F to 140°F. A frozen seawater hydraulic system must be thawed prior to use. Once a seawater system is operating, waste heat keeps the seawater from refreezing. This is particularly true for a conventional open loop circuit where recycling keeps the fluid temperature above freezing. If the situation warrants, an environmentally friendly glycol additive could be used in the system to lower the freezing point.

In comparison to oil, water has a narrow viscosity range making it an ideal fluid for a hydraulic system. While the kinematic viscosity of a general purpose hydraulic oil (MIL-H-5606) may undergo a 35 to 40 centistokes decrease over a 100°F increase in temperature, water undergoes less than a 2 centistokes change. Because water does not thin out like hydraulic oil as it gets hotter, water hydraulic components tend not to loose volumetric efficiency caused by increased internal leakage.

Manufacturers of oil hydraulic equipment recommend a fluid operating temperature range of 40°F to 140°F, the oil must be heated and gradually circulated to prevent system damage. Hydraulic fluid additives help ensure (within the temperature envelope) that the oil viscosity will not be too thick for cold weather startup or too thin for warm weather operation. As temperature increases, these additives break down and the hydraulic fluid looses its desired properties.

Between the extremes of freezing and boiling, seawater provides a much larger operating temperature range from about 40°F to 180°F. Within this range, viscosity is relatively constant and there is no need for additives.

8.0 CONCLUSIONS

The following conclusions have been drawn as a result of this demonstration of the seawater hydraulic-powered CCN-150 transfer pump:

1. The Fenner F60 seawater motor is a good replacement for the existing Rexroth oil hydraulic motor. The F60 weighs 4 pounds more than the Rexroth motor but application of composite technology to the motor housing may eliminate this weight disadvantage.

2. Volumetric, mechanical, and overall efficiencies showed that the Fenner F60 seawater motor has a lower than expected overall efficiency for a positive displacement piston motor. At an overall efficiency of 75 percent, the F60 motor has a 15 percent lower efficiency than the Rexroth it replaces. A specific cause for this low performance was not determined. This low efficiency may be attributed to this first generation of the F60 size motor. If this low efficiency is a true characteristic of the larger horsepower seawater motors, then more horsepower will be

required to maintain equivalent capability. This may result in a larger power source and could partially offset other weight savings.

3. The use of thermoplastic hose provides a total weight savings of 1.8 pounds per foot length of the three hydraulic hoses (supply, return, and drain). The 1-inch-diameter Synflex thermoplastic hose showed excellent abrasion characteristics and experienced no appreciable wear over the test period for the seawater hydraulic-powered CCN-150 transfer pump. The 1-inch-diameter Synflex hose did show a tendency to kink making handling characteristics less than desirable.

4. Testing at the limit of the available power supply, the seawater hydraulic-powered CCN-150 transfer pump showed lower discharge pressures across the flow range compared to the oil hydraulic-powered CCN-150. This variation is most likely due to the transfer pump housing modifications necessary to accommodate the Fenner F60 motor. These modifications apparently increased turbulence within the pump, producing the additional pressure drop.

5. Using the affinity law relationship for centrifugal pumps, the full flow performance for the seawater hydraulic-powered CCN-150 transfer pump was extrapolated from 2,150 rpm to 2,400 rpm in order to compare against the oil hydraulic-powered transfer pump data. Based on this scaling, approximately 76-brake horsepower is required to achieve full seawater hydraulic-powered CCN-150 transfer pump performance. The Fenner F60 seawater motor is capable of this performance (52 gpm at 2,500 psi).

6. A seawater hydraulic power source can be designed with available technology to meet a 52-gpm flow rate at 2,500-psi pressure (76 horsepower) for full transfer pump performance. Selection of a larger displacement piston pump design from Fenner is the likely candidate to produce the required flow and pressure. The power source weight would be comparable to the Coast Guard lightweight power source built around the Deutz engine. Conversion of the hydraulic starting system is also within the available technology. Selection of a smaller displacement Fenner motor would be adequate for such a conversion.

9.0 RECOMMENDATIONS

The following recommendations are presented based on the results and conclusions of the Phase II demonstration of the seawater hydraulic-powered CCN-150 transfer pump:

1. The Composite Machinery Group at the Carderock Detachment of the Naval Surface Warfare Center (CDNSWC), Annapolis, Maryland, has developed lightweight components for the CCN-150-5C transfer pump. Incorporating the Fenner F60 motor into this composite CCN-150-5C is recommended to bring these parallel technology efforts together. Consultation with CDNSWC Annapolis to assist NFESC in the development of a lighter weight Fenner motor is also recommended to achieve maximum weight reduction. Development of this prototype CCN-150 transfer pump should also include streamlining flow passages to minimize internal pump losses.

2. Development of a prototype 85-horsepower seawater hydraulic power source capable of operating the modified CCN-150-5C transfer pump is recommended. This prototype power source should include evaluation of a larger displacement seawater pump to serve the prime mover and of a small displacement seawater motor to provide hydraulic starting capabilities. Application of composites should be included were appropriate to reduce weight without detracting from robustness.

10.0 REFERENCES

1. Naval Civil Engineering Laboratory. Technical Report R-936: Seawater hydraulics: a multi-function tool system for U.S. Navy construction divers, by S. Black and J. Kunsemiller. Port Hueneme, CA, May 1991.

2. Naval Sea Systems Command. NAVSEA S6225-DX-MM0-010: Technical manual, Submersible pump subsystem CCN-150. Washington, DC, 15 Aug 1980.

Appendix A

FENNER F60 MOTOR DATA

FENNER F60 MOTOR DATA

7/15/95 Data

Speed (rpm)	Torque (ft-lbs)	Supply Flow (gpm)	Supply Pressure (psi)	Return Pressure (psi)	Case Drain (gpm)	Input (hp)	Output (hp)	Overall Eff (%)	Theoretical Flow (gpm)	Volumetric Efficiency (%)	Theoretical Torque (ft-lb)	Mechanical Efficiency (%)	Overall Eff (%)
1140	21.0	17.5	500	10	1.2	5.0	4.6	91.1	21.2	error	27.9	75.2	error
1490	19.0	31.0	500	35	1.4	8.4	5.4	64.1	27.7	89.3	26.5	71.7	64.0
2400	13.5	52.0	500	80	2	12.7	6.2	48.4	44.6	85.7	23.9	56.4	48.3
1010	50.0	16.5	1000	10	1.4	9.5	9.6	error	18.8	error	56.4	88.6	error
1280	50.0	27.5	1000	30	1.6	15.6	12.2	78.3	23.8	86.4	55.3	90.4	78.2
2280	42.0	48.5	1000	70	2	26.3	18.2	69.3	42.3	87.3	53.0	79.2	69.2
740	75.0	15.0	1500	10	1.6	13.0	10.6	81.0	13.7	91.6	84.9	88.3	80.9
1220	78.0	27.5	1500	25	2	23.7	18.1	76.6	22.7	82.4	84.1	92.8	76.4
2100	74.5	45.0	1500	60	2	37.8	29.8	78.8	39.0	86.7	82.1	90.8	78.7
650	99.0	13.5	2000	10	1.8	15.7	12.3	78.2	12.1	89.4	113.4	87.3	78.0
1100	100.0	25.0	2000	20	2	28.9	20.9	72.5	20.4	81.7	112.9	88.6	72.4

7/16/95 Data

Speed (rpm)	Torque (ft-lbs)	Supply Flow (gpm)	Supply Pressure (psi)	Return Pressure (psi)	Case Drain (gpm)	Input (hp)	Output (hp)	Overall Eff (%)	Theoretical Flow (gpm)	Volumetric Efficiency (%)	Theoretical Torque (ft-lb)	Mechanical Efficiency (%)	Overall Eff (%)
780	22.5	18.7	500	10	1.4	5.3	3.3	62.5	14.5	77.5	27.9	80.6	62.4
1720	20.0	37.5	500	45	1.6	10.0	6.5	65.8	31.9	85.2	25.9	77.1	65.7
2480	13.7	51.0	500	80	1.8	12.5	6.5	51.8	46.1	90.3	23.9	57.2	51.7
700	50.0	17.0	1000	8	1.6	9.8	6.7	67.7	13.0	76.5	56.5	88.4	67.6
1600	49.0	34.0	1000	38	2	19.1	14.9	78.2	29.7	87.4	54.8	89.4	78.1
2280	43.7	47.5	1000	70	1.8	25.8	19.0	73.6	42.3	89.1	53.0	82.4	73.5
630	77.0	16.0	1500	5	1.7	14.0	9.2	66.2	11.7	73.1	85.2	90.4	66.1
1480	81.0	31.0	1500	35	2	26.5	22.8	86.1	27.5	88.7	83.5	97.0	86.0
2100	75.0	44.0	1500	60	2	37.0	30.0	81.1	39.0	88.6	82.1	91.4	81.0
525	103.0	15.0	2000	2.5	1.8	17.5	10.3	58.9	9.8	65.0	113.9	90.5	58.8
1360	106.0	30.0	2000	30	2.5	34.5	27.4	79.6	25.3	84.2	112.3	94.4	79.5
1880	111.0	41.0	2000	missing	3	error *	39.7	error *	34.9	85.2	error *	error *	error *

Theoretical Torque(N-M)=Pressure(bars)*Displacement (cc/rev) / (20(PI))

* Error due to missing data.

5/22/95 Data

Speed (rpm)	Torque (ft-lbs)	Supply Flow (gpm)	Supply Pressure (psi)	Return Pressure (psi)	Case Drain (gpm)	Input (hp)	Output (hp)	Overall Eff (%)	Theoretical Flow (gpm)	Volumetric Efficiency (%)	Theoretical Torque (ft-lb)	Mechanical Efficiency (%)	Overall Eff (%)
One Harben Unit													
890	4.5	17.5	175	40	0.2	1.4	0.8	55.3	16.5	94.4	7.7	58.5	55.2
860	10.9	17.5	175	40	0.2	1.4	1.8	error *	16.0	91.3	7.7	error *	error *
820	15.0	16.2	350	40	0.2	2.9	2.3	79.9	15.2	94.0	17.7	84.9	79.8
800	20.3	16.2	475	40	0.2	4.1	3.1	75.2	14.9	91.7	24.8	81.9	75.1
780	26.2	16.2	575	40	0.2	5.1	3.9	77.0	14.5	89.4	30.5	85.9	76.8
760	30.9	16.0	675	40	0.2	5.9	4.5	75.4	14.1	88.2	36.2	85.4	75.3
720	41.5	15.0	875	40	0.2	7.3	5.7	77.9	13.4	89.1	47.6	87.2	77.7
Two Harben Units													
1560	13.7	30.0	425	60	0.2	6.4	4.1	63.7	29.0	96.6	20.8	65.8	63.6
1480	19.8	28.5	500	60	0.2	7.3	5.6	76.3	27.5	96.4	25.1	78.9	76.1
1385	30.0	27.5	700	55	0.2	10.3	7.9	76.4	25.7	93.5	36.8	81.6	76.3
1280	61.0	26.0	1200	50	0.2	17.4	14.9	85.2	23.8	91.4	65.6	93.1	85.1
1180	75.0	25.0	1500	50	0.2	21.1	16.9	79.7	21.9	87.7	82.7	90.7	79.5

* Calculation error is the result of data collection error.

Theoretical Torque(N-M)=Pressure(bars)*Displacement (cc/rev) / (20(PI))

Data taken from NAVSEA S6225-DX-MMO-010 dtd 15 Aug 1980

CCN-150 Performance for Water

Hydraulic Supply Conditions:
Supply (psi) - 2,000 to 2,300
Return (psi) - 125 to 130
Flow (gpm) - 45 to 47

Flow (gpm)	Discharge Pressure (psig)
0	80
200	76
400	72
547	70
600	68
800	62
1000	58
1200	51
1400	46
1600	41
1653	40
1823	20

Empirical Data taken 7/7/95 at NFESC

Speed (rpm)	**Motor Supply Pressure (psi)**	**Motor Supply Flow (gpm)**	Input Hydraulic (hp)	**CCN150 Discharge Flow (gpm)**	**CCN150 Discharge Head (psi)**	Output Hydraulic (hp)	Overall Performance Efficiency (%)
858	300	19	3.3	388	5	1.1	34.0
842	350	19	3.9	202	9	1.1	27.3
1342	700	29	11.8	635	15	5.6	46.9
1333	750	29	12.7	492	20	5.7	45.2
1330	800	29	13.5	335	25	4.9	36.1
1729	1150	37	24.8	1375	15	12.0	48.5
1796	1225	37	26.4	1340	20	15.6	59.1
1796	1225	37	26.4	758	30	13.3	50.2
1724	1300	37	28.1	405	40	9.5	33.7
1719	1350	37	29.1	441	45	11.6	39.7
2158	1775	46	47.6	1693	13	12.8	27.0
2135	1775	46	47.6	1640	20	19.1	40.2
2158	1750	46	47.0	1499	30	26.2	55.9
2181	1725	46	46.3	1040	40	24.3	52.4
2173	1825	47	50.0	846	50	24.7	49.3
2105	1900	46	51.0	529	60	18.5	36.3
2127	1950	45	51.2	917	65	34.8	67.9

Scaling Empirical Performance to: 2400 rpm

Calculated Using Affinity Laws

CCN150 Discharge Flow (gpm)	CCN150 Discharge Head (psi)	Delivered Hydraulic (hp)	*Calculated* Absorbed Power * (hp)
1882.9	16.1	17.7	65.5
1843.6	25.3	27.2	67.7
1667.1	37.1	36.1	64.6
1144.4	48.4	32.3	61.7
934.4	61.0	33.2	67.4
603.1	78.0	27.4	75.6

* Calculated absorbed power performed using overall efficiency.

Shaded region outlines data used to scale CCN-150 performance.

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